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The utility of travelling when destinations are heterogeneous. How much better is the next destination as one travels further?

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Abstract. In many studies travel behaviour (for example, commuting) is analysed on the basis of a utility function with the distance (d) travelled as one of the arguments. An example is U = U(d,Y-cd,T-td) where Y and T denote money and time constraints, and c and t money and time costs per unit distance. This standard approach is not without problems, however, since it ignores the fundamental fact that most transport has a derived character: travelling kilometres is not an activity that gives utility per se, but only because these kilometres bring people to certain places they want to visit. In this paper we develop a method that provides a justification for utility functions such as shown here by showing that these can be made consistent with theories that take into account the derived character of transport.

Implications of our approach are discussed for commuting distances of different types of jobs. Our approach gives an explanation for the paradox that highly educated workers tend to have long commuting distances. Given their high value of time one would expect short commuting distances, but the low spatial density of their jobs appears to dominate the outcome.

Key words: rectangular city, commuting, distance distributions

JEL classification: C15, R14, R41

1 Introduction

It is common wisdom that travel demand has mainly a derived character: People usually do not travel for the fun of it[1]. Instead, people travel in order to reach certain destinations where they want to carry out certain productive

[1] For a counter view we refer to Mokhtarian and Salomon (1999).

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or consumptive activities. This common fact is, however not reflected in the way travel demand is modelled in many studies of travel behaviour. Consider for example the following formulation of a utility function that is often used as a basis for the analysis of travel demand. In such studies (see for example Golob et al. 1981; De Jong 1989,1990; McCarthy 2001; Van Vuuren and Rietveld 2002), travel behaviour is analysed on the basis of a utility function with the distance, say d, travelled as one of the arguments. An example is

$$U = U(d, Y\text{-}cd, T\text{-}td), \tag{1}$$

where Y and T are money and time budgets, and c and t are the money and time costs per unit distance. The first argument of the utility function relates to the benefits of a trip of a certain distance d, the second concerns the benefits of consuming other goods than transport (Y-cd equals the amount of money available for this after transport expenditures have been subtracted). The third term of the utility function concerns the total time available after time for travelling has been subtracted. The partial derivatives of U with respect to its three arguments are assumed to be positive. As indicated by Small (1992, p 12) the theoretical foundation of this formulation is not entirely clear, however. One of the problems is that it ignores the derived character of transport: travelling kms is not an activity that gives utility per se, but only because these kms bring people to certain places they want to visit. The utility function as specified in (1) can be used to derive a demand function for transport where the distance travelled per time period is explained by factors such as the price of transport, the travel time involved and income:

$$d = d(c,t,Y) \ .$$

Demand functions of this type are often used to estimate price and income elasticities of travel demand (for a review, see Oum et al. 1992; Kreemers et al. 2002). They are an important basis for policy studies where effects of changes in fuel prices or public transport fares on travel demand are analysed. Given the derived nature of travel demand one would have expected a utility formulation such as:

$$U = U(v, Y\text{-}cd, T\text{-}td), \tag{2}$$

as a basis for the analysis. In this utility formulation v represents the gross[2] utility of a visit to a certain destination at distance d.

In this paper we give a justification for utility functions such as (1) by showing that these can be derived from formulations of type (2). We also indicate some pros and cons of both formulations and discuss implications for the differences in commuting distances of workers. In addition we investigate the impact of urban form and spatial density on the utility of travelling.

The reason that these problems emerge is that the spatial context within which travel behaviour takes place has not been made explicit in this modelling approach. It should be emphasised that there exists a broad literature on transport modelling where this problem is adequately addressed

[2] The gross utility is the utility of the outdoor activity without taking into account the money and time outlays related to the trip.

(see for example Ortuzar and Willumsen 2001 and Hensher and Button 2000). Trip distribution models (at the aggregate level) and destination choice models (at the disaggregate level) usually contain an explicit trade-off between the utility of a visit (often in stochastic terms to take into account unobserved heterogeneity) and the costs of a trip. Such multi-stage transport models can avoid the problems mentioned above because of the explicit spatial representation of alternative destinations.

The utility and demand functions described above can be considered as a reduced form of these more extensive multi-stage transport models. The main reason why such reduced form models are used is data availability. For example in the context of the analysis of demand for car kilometres data often relate to total number of kilometres travelled per year without knowledge of the destinations visited. When data on destinations would be given, an explicit destination choice component can be included and the above mentioned problems can be avoided. Such an explicit analysis of the various aspects of travel behaviour is obviously superior to the approach outlined above. But when such data are not available, destination choice remains implicit. This paper sets out to investigate how alternative assumptions about spatial distributions of destinations have an impact on travel demand.

A spin off of our approach is that it provides a useful framework for the analysis of differences in travel distance distributions –and more in particular average travel distances– for various types of travellers. Our analysis makes explicit how average travel distances depend on travel costs and on spatial densities of destinations. This sheds light on the ‘paradox’ observed in many urban areas that highly skilled workers –who tend to have high values of time– do not have short commuting distances as one might expect, but that the contrary happens to be the case (see for example Rouwendal and Rietveld 1994; Van Ommeren 2000). This topic will be addressed in Sect. 4.

2 Individual level

Consider an individual who can visit a number of destinations (for example, job locations) at various distances from his residence (point of origin). We assume that he makes one visit per time unit. The total number of potential destinations within a certain maximum distance D is M. The alternatives are ranked in increasing distance from the origin to the destination: $d_1, \ldots, d_M$. The corresponding gross utilities are $v_1, \ldots, v_M$. Consider a certain distance d^+. Let $n \leq M$ index the destination with the longest distance d_n being shorter than d^+. Then the maximum gross utility derived from a trip with distance d^+ equals

$$v(d^+) = \max\{v_1, \ldots, v_n\}$$

When we compare two distances d^+ and $d^+ + \varepsilon$ with $\varepsilon > 0$, we find that

$$v(d^+ + \varepsilon) \geq v(d^+) \ .$$

Thus we arrive at a monotone non-decreasing function. The case of $v(d^+ + \varepsilon) = v(d^+)$ occurs when one of the two following conditions holds:

(i) There is no potential destination with a distance between d^+ and $d^+ + \varepsilon$.

(ii) There are one or more potential destinations with a distance between d^+ and $d^+ + \varepsilon$, but these additional destinations have a utility lower than or equal to $v(d^+)$. The form of the function $v(d^+)$ is as presented in Fig. 1.

The points at the upper corners of $v(d^+)$ in Fig. 1 form together the set of non-dominated alternatives. The destinations below the line in Fig. 1 are dominated by destinations on the line. The individual will never choose an alternative below this line. By deleting the dominated alternatives we arrive at a one-to-one relationship between utility levels and distance travelled. The function $v = z(d)$ as presented in Fig. 1 can be translated into $d = z^{-1}(v)$ where the function z^{-1} is defined in the points v for which an observation exists. Consider an individual at i evaluating a destination j. Then the basic utility function already introduced above

$$U_{ij} = U(v_i, Y\text{-}cd_{ij}, T\text{-}td_{ij}), \tag{2'}$$

can be reformulated as

$$U_{ij} = U[z(d_{ij}), Y\text{-}cd_{ij}, T\text{-}td_{ij}] \tag{3}$$

Equation (1) is a rewritten version of Equation (3) with one difference: (3) is only defined in particular points (i.e., the distances corresponding to the non-dominated points in Fig. 1), whereas for Equation (1) such an explicit limitation has not been introduced. In the next section we will demonstrate how the gap between these two can be bridged.

3 Utility of visits for an average traveller in a uniform space of infinite size

Figure 1 gives a possible result of the relationship between distance travelled and utility for the particular spatial setting for one specific individual. One may wonder how the transformation between utility and distance would look like for the average individual. We will give a derivation based on the assumption of uniform density of locations in two-dimensional space and uniform density of the utility of visiting a destination. Consider locations in two-dimensional space that are uniformly

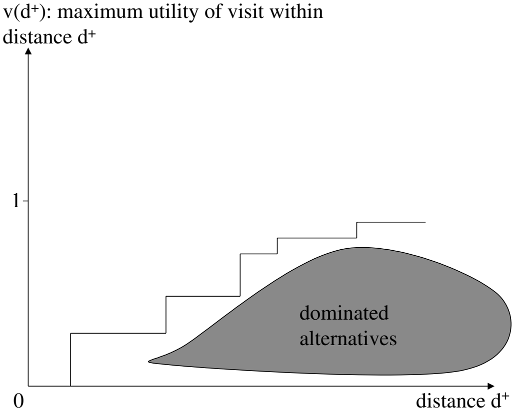

Fig. 1. Maximum utility of visiting a destination within a certain distance d^+

distributed with density $M/(\pi D^2)$. This means that the expected number of destinations in a circle with radius D equals M. Also individuals are assumed to be distributed uniformly across space. The two distributions are assumed to be independent. Consider a randomly drawn individual with a circle of radius D around it. Then distances to the destinations located in the circle are a random sample of the following uniform distribution[3]:

$$f(d) = 2d/[D^2] \qquad \text{with} \quad 0 \le d \le D \ .$$

This function clearly displays that in a circle the density of destinations increases with the distance from the origin. The cumulative distribution F(d) is:

$$F(d) = d^2/D^2 \qquad \text{with } 0 \le d \le D \ . \tag{4}$$

Then, when the individual considers locations within a distance d, the expected number of potential destinations equals Md^2/D^2. Therefore, the expected number of potential destinations *increases quadratically* with distance travelled. Thus, the *elasticity of the number of potential destinations with respect to distance travelled equals 2*. The quadratic form obviously follows from the assumption of a two-dimensional space. When the individual can only make visits in a one-dimensional space (all destinations are located along one road), the number of potential destinations would be *proportional* to the distance travelled.

These results make clear that a longer trip yields potential benefits because it leads to a larger choice set, and hence to adding an especially attractive alternative to the choice set. Assume that the utility v of a visit to a particular destination (apart from transport costs) has a uniform distribution g(v) with values between a and 1: the values of a and 1 are the lower limit and upper limit of the utility level. For a commuter considering various vacant positions the utility u depends on the wage offered, and on other determinants of job attractiveness. Thus,

$$g(v) = 1/[1-a] \qquad \text{with} \quad a \le v \le 1 \ .$$

The corresponding distribution function G(v) equals:

$$G(v) = [v-a]/[1-a] \qquad \text{with} \quad a \le v \le 1 \ . \tag{5}$$

Note that heterogeneity decreases as a gets closer to 1. If a would be exactly equal to 1, all destinations would yield exactly the same level of utility. In that case the individual would of course always choose the nearest destination. Suppose that the individual can choose out of n potential destinations ($n \le M$). Let the destinations be ranked in increasing order: $v_1, \ldots, v_n$. Then it follows from the theory of order statistics (Mood and Graybill 1963) that the distribution of the utility of the best alternative v_n, $h(v_n)$, equals:

$$\begin{aligned} h(v_n) &= [n!/(n-1)!][G(v_n)]^{n-1} g(v_n) \\ &= n[1-a]^{-n}[v_n - a]^{n-1} \qquad \text{with} \quad a \le v_n \le 1 \ . \end{aligned} \tag{6}$$

Then the expected utility value of the best alternative among these *n* is equal to:

[3] For the ease of presentation we ignore the problem that individuals near the 'edge' will have fewer potential destinations since the space is empty on the other side. Thus, the space is assumed to be of infinite size.

$$E(v_n) = \int_a^1 n[1-a]^{-n}[v_n - a]^{n-1} v_n dv_n = [n+a]/[n+1] \quad n = 1,2,3,\ldots,M \,. \tag{7}$$

From Eq. (7) it follows that *the elasticity of the expected maximum utility of a trip with respect to the number of alternatives* n *from which can be chosen equals* [n(1−a)]/[(n + a)(n + 1)]. This elasticity strongly decreases with the number of alternatives. For example, when a = 0 and n = 1, the elasticity equals ½, but for larger values of n it gets close to 0[4]. When we confront this result with the constant elasticity of value 2 of the number of potential alternatives with respect to distance, it is clear that with longer distances the relative gains of searching at even longer distances get very small[5].

For a more detailed analysis of distance travelled on utility, consider an individual who wants to make a trip within a distance d. Based on a spatial density of destinations $M/(\pi D^2)$, the expected number of destinations within distance d is Md^2/D^2. Then, the number of destinations n within a distance d from the individual has the following Poisson distribution:

$$k(n,\, d) = \exp(-Md^2/D^2)(Md^2/D^2)^n/n! \qquad n = 0, 1, 2, 3, \ldots \tag{8}$$

where k(n, d) is the probability that there are n destinations within distance d. Since we only consider situations where at least one destination is found the result n = 0 must be excluded so that the probability k(n, d) has to be redefined as:

$$k'(n, d) = [\exp(-Md^2/D^2)(Md^2/D^2)^n/n!]/[1 - \exp(-Md^2/D^2)] \quad n = 1,2,3,\ldots \tag{8'}$$

Assume that the distribution of distances f(d) and the distribution of utilities g(v) are independent. Then the expected value of a trip with distance d (denoted as E[v(d)]) is:

$$\begin{aligned} E[v(d)] = \sum_{n=1,2,3\ldots} &[(n+a)/(n+1)] \\ &\times [\exp(-Md^2/D^2)(Md^2/D^2)^n/n!]/[1 - \exp(-Md^2/D^2)] \,. \end{aligned} \tag{9}$$

In the special case that M goes to infinity, E[v(d)] equals 1 for all positive d. This is a plausible result: when there is a very high spatial density of potential destinations one will easily find a very good destination nearby without the

[4] This result obviously depends on the form of the density function g(v). We have chosen the uniform density here because an analytical expression exists for its distribution function which is convenient when dealing with order statistics (see Equation (6)). Only in the case of distribution functions with a thick tail one may expect that increasing the number of alternatives would have substantial effects on the expected maximum attainable utility.

[5] Given a search distance d and number of destinations n, an increase in the search distance with 1% leads to 2% more alternatives. But these lead to an increase of only 2[n(1-a)]/[(n + a)(n + 1)]% in utility.

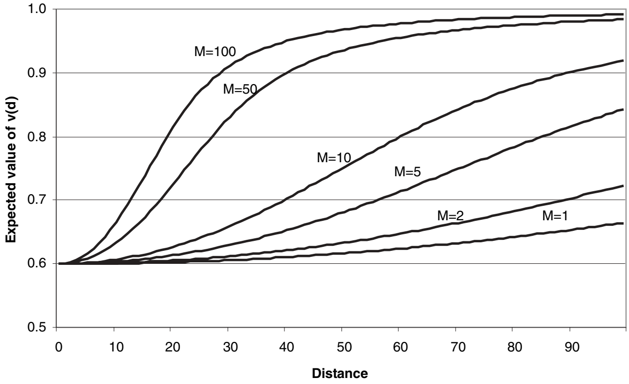

Fig. 2. Utility of a trip as a function of distance and the number of potential destinations; based on uniform distribution of utility (0.2 to 1.0) and based on uniform density in space with circular distance function

need to travel long distances. In the case that the spatial density equals 1 in a circle with radius D (M = 1), E[v(d)] is slightly ascending with distance[6]. The expected value for a trip with distance d = 0 equals [1 + a]/2. For d = D we find that the expected utility of a trip is close to 1 for larger values of M. This is again a credible result: when a large number of potential destinations exists, the expected utility value of the best alternative is close to the maximum possible value of 1.

In Fig. 2 some results are presented for the expected utility of the trip as a function of the number of alternatives M (values are given for 1, 2, 5, 10, 50, 100) and distance d (d ranges from 0 to D = 100). The value of the utility parameter a has been set equal to 0.2. As indicated above two countervailing forces influence the curve's shape. First, an increase in distance d leads to a more than proportional increase in the number of alternatives (the area of a circle is a quadratic function of its radius). This would lead to *convex* curves. Second, an increase in the number of alternatives leads to higher expected utility values, but the increase fades away as the number of alternatives gets higher. The second effect would lead to a *concave* curve. From Fig. 2 it appears that only in the case that M = 2 or slightly higher the final curve has a pure convex form. In all other cases the curves are characterised by an inflection point separating a segment with increasing slopes from a segment with decreasing slopes. Pure concave shapes are never found.

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[6] Note that when there would be exactly one destination in the circle, the expected utility is the mean value between a and 1 and we would arrive at a horizontal line at the level (a + 1)/2. However, since we assume a Poisson process some individuals may end up with zero destinations and some with more than one destination. In the case of zero destinations there is simply no trip and no utility of a trip and this possibility has therefore been ruled out in Eq. (8'). In the case that there will be more than one destination found the expected value is very close to (a + 1)/2 for short distances because then there is most probably only one destination. However, for longer distances the probability of more than one destination increases and so does the expected value of a trip.

4 Utility of visits for an average individual in a uniform space, rectangular city

The above analysis is based on the assumption that the space has infinite size so that the issue of individuals being located at the edge of an urban area having fewer destinations than individuals in the centre does not arise. As a consequence of this assumption an increase in the distance travelled always leads to a more than proportional increase in the number of potential destinations. In the real world with its distinct cities, this is not realistic. Therefore we repeat our analysis for some specific urban forms. We start with the assumption of a rectangular city. This city consists of a grid of say $1{,}000 \times 1{,}000$ points. Each point represents an individual. Thus there are one million individuals. A set of M destinations is randomly distributed among the grids according to the uniform distribution.

For the above described spatial setting it is difficult to give a theoretical derivation, therefore we adopt a simulation approach. We draw a certain individual in a random way. His location appears to be grid i,j. This grid is labelled k_0. Then we draw M other grids that are randomly distributed among the grids. These grids are labelled $k_1, \ldots, k_M$. The distances of these grids to k_0 are $d_1, \ldots, d_M$. The distances are computed as city block distances:

$$d[(x_1, y_1), (x_2, y_2)] = |x_1 - x_2| + |y_1 - y_2|$$

The next step is that we rank the M distances in increasing order, which results in $d_1^*, \ldots, d_M^*$. Then we draw M utility values from the distribution g(v), which results in $v_1, \ldots, v_M$. We are now able to compute the maximum utility w of a certain trip as a function of the distance d travelled. This maximum utility is not defined for distances between 0 and d_1^*. For distances that are larger than d_1^* we compute this maximum utility as follows:

$$w(d) = \max\{v_1, \ldots, v_n\} \text{ where } d_n^* \leq d \leq d_{n+1}^* \ .$$

We repeat this procedure 10,000 times in order to get results for an aggregate traveller similar to the approach followed in Sect. 3. Now we are able to compute the average value of w(d) for all 10,000 iterations in the points $d = 0, 1, 2, \ldots, 1998$ (1998 is the maximum possible distance according to the city block distance).

In Fig. 3 some results are presented for the expected maximum utility of a destination as a function of the number of alternatives M (values are given for $M = 1, 2, 5, 10, 50, 100$) and distance d (d ranges from 0 to 1998). The value of the utility parameter a has again been set equal to 0.2. We see that for distances between 0 and 100 the curve pattern is rather unstable. This is due to the fact that the curve is based only on 10,000 iterations and that the probability of a distance lower than 100 between the randomly drawn individual and a randomly drawn destination is very small. All curves have a sigmoid shape: the expected marginal utility of distance of a trip starts at a low level, as distances increase it gets higher, but finally it declines again. A regular pattern of inflection points appears: as there are more destinations the transition from increasing to decreasing marginal utilities of distance take place at shorter distances.

When we compare Fig. 3 and Fig. 2, we note that for $M = 1$ Fig. 3 shows a curve that is equal to the constant $[1 + a]/2$, Fig. 2 on the contrary shows a slightly ascending curve for $M = 1$. The reason for this difference is that in the

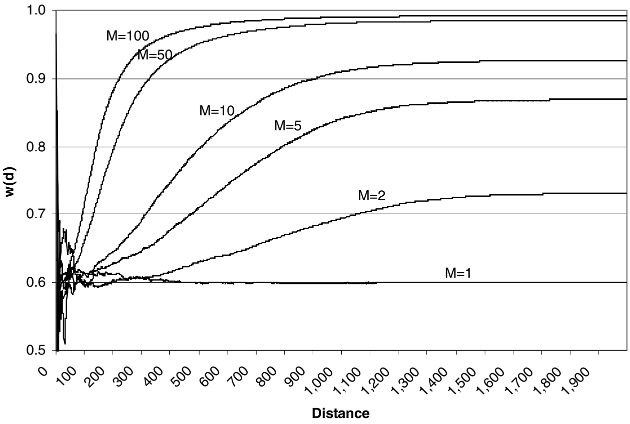

Fig. 3. Expected maximum utility level of a destination, assuming there are one or more destinations, as a function of the distance and the number of potential destinations; based on uniform distribution of utility (0.2 to 1.0) and based on uniform density in space, in a 1000 × 1000 rectangular city

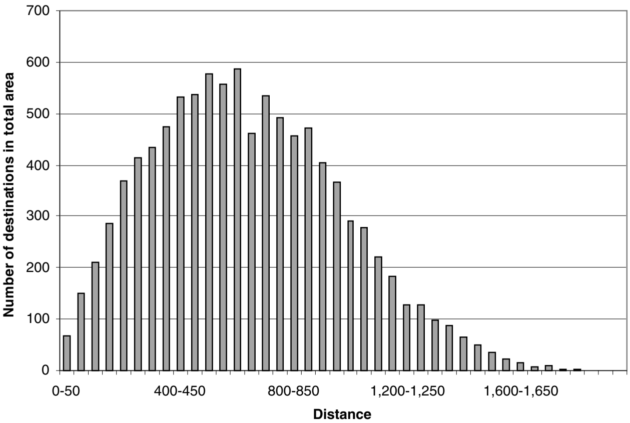

Fig. 4. The density of distances to potential destinations, assuming a 1,000 × 1,000 grid

simulation we took care that for $M = 1$ there was exactly one potential destination within the maximum distance D, in that way we just find that the expected utility of the trip equals the expected utility of any destination being the mean value between a and 1. The reason that in Fig. 2 for $M = 1$ the curve slightly ascends has been explained earlier. Another difference between Fig. 3 and Fig. 2 is that for $M = 2$, Fig. 2 yields an inflection point, whereas Fig. 3 does not. This is because of the finite size of the spatial setting. Because of this finite size, the expected number of potential destinations doesn't increase quadratically with distance travelled, but slightly less and for very long distances the number of potential destinations hardly increases (see Fig. 4). Note that in section 3 the density of potential destinations is proportional to distance (see Eq. (4)), whereas Fig. 4 yields a bell shaped pattern.

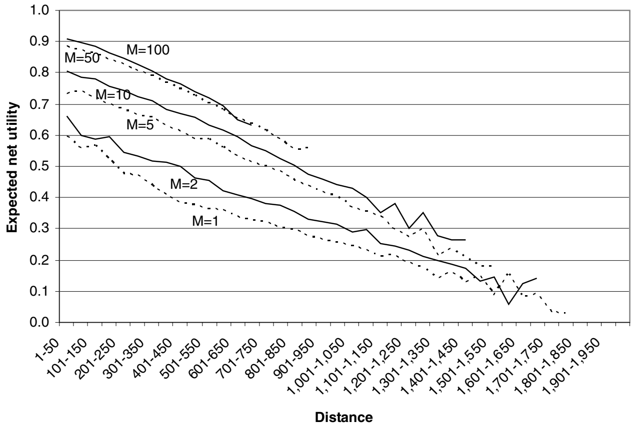

Fig. 5. Expected net utility of the best destination as a function of distance and the number of potential destinations, based on uniform density in space, which is a 1,000 × 1,000 rectangular city

We conclude that although the assumptions on the spatial structure are different, the final result for the relationship between distance and utility of a trip is rather similar. Only when there is a very small number of potential destinations the curves are somewhat different. Thus, the shortcut applied in utility function (1) is defendable in the situation that no data are available at the individual level on the locations and qualities of the available destinations.

Having established the relationship between distance travelled and average utility, it is also possible to derive some additional results on travel patterns. For example, one can easily derive the expected utility of the most preferred trip as a function of distance. For this purpose we have of course to take into account the transport costs. We assume that the cost per unit distance is such that the cost level at the maximum distance ($d = 1998$) equals 1. Thus we arrive at a cost of 1/1998 per unit distance.

For each iteration we determine the most preferred trip by solving the following problem in order to derive the distance j with the highest net utility $v_j - cost_j$:

$$\max_j\{v_j - cost_j\} \qquad j = 0, 1, \ldots, 1998 \ .$$

Thus we gather 10000 distances with associated net utilities. From these net utilities we can compute the level of expected net utility of the best destination (see Fig. 5).

Note that the curves are declining with distance. With the given level of transport costs it appears that as the best alternative lies further away the transport costs increase faster than the ‘gross’ utility of the trip. Note, however, that this result depends on the level of the transport costs. When transport costs would be close to zero the resulting patterns of expected net utilities would be very similar to the ones found in Fig. 3.

Another result that can be derived from these inputs is the distribution of destinations with the highest net utility according to distance. As Fig. 6b

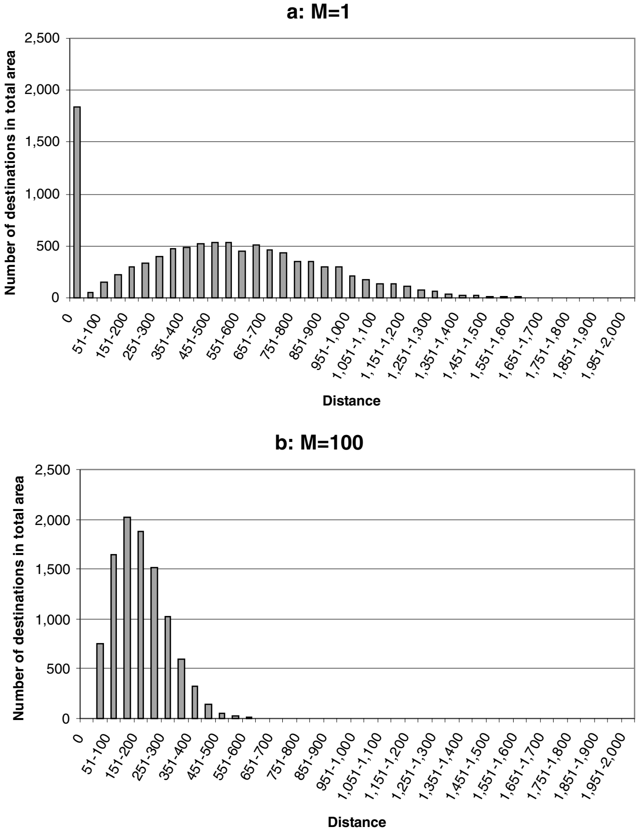

Fig. 6a, b. The distribution of destinations with the highest net utility according to distance, based on uniform density in space, which is a $1{,}000 \times 1{,}000$ rectangular city

shows the density is close to the origin when the number of potential destinations M is large (for example, $M = 100$). When M is small (for example, $M = 1$) the density has a very wide range (see Fig. 6a). Thus, when people are searching for a scarce good or service the average distance travelled will be much higher. Note also that when M is small there will also be many persons who will not find a destination with a positive net utility: the utility of the feasible alternatives is always smaller than the costs of getting there[7].

When we compare Fig. 6 and Fig. 4, Fig. 4 can be interpreted as the distribution of destinations with the highest net utility according to distance when transport costs were zero. We see that when transport costs are zero the density has a very wide range. This is due to the fact that in that case, people would consider every alternative and choose the one with the highest utility, even when the distance to that alternative is very large.

[7] This can be inferred from the mass of the density in $d = 0$, reflecting the share of people that will not participate.

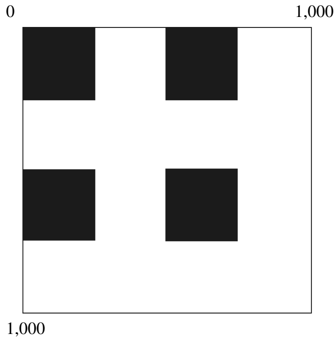

Fig. 7. Example of a polycentric urban area

When we compare two groups of households, one with high transport costs and one with low costs, these figures show that the group with high transport costs has a lower average travel distance. Thus, one may expect workers with a high value of travel time to have shorter commuting distances than persons with a low value of travel time. However, this is not what one often observes. Empirical commuting distances suggest the opposite pattern with long commuting distances for highly skilled workers, who tend to have high values of time (Rouwendal and Rietveld 1994; Van Ommeren 2000). Various explanations may be put forward to explain this paradox. For example, two worker households may be over-represented in the group of highly skilled workers and these may have more difficulty in finding a good match between place of residence and the work places of both workers. Another explanation relates to specific spatial structures in urban areas when the locations of the best jobs are far away from the best residential areas. Our approach suggests still another explanation. For highly skilled workers the total number of suitable jobs is much smaller than for lowly skilled workers and, comparing Fig. 6b (M = 100) with Fig. 6a (M = 1), it appears that the average commuting distance decreases when the number of alternatives is higher. A related explanation is that for highly skilled persons the heterogeneity of jobs is larger (the range 1-a of utility values is broad). Such a broad range of outcomes has a similar boosting effect on commuting distances.

5 Utility of visits for an average individual in a polycentric urban area

The above analysis is based on the assumption that the relevant urban area has a uniform density and a rectangular space. One may wonder whether other urban forms would lead to different results. Therefore we also carry out an analysis for a rectangular polycentric urban area.[8] We repeat the procedure as described in section 4 for a specific urban system with 4 centres (see Fig. 7).

[8] This means for the simulation that we consider the same $1{,}000 \times 1{,}000$ grid, but when we run the simulation we take care that when we draw the individual and the set of M destinations some grids are drawn with chance zero (the empty areas). In this way one can simulate practically every urban structure.

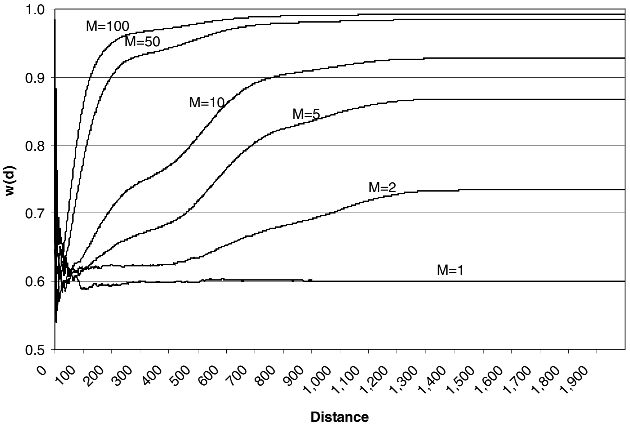

Fig. 8. Expected maximum utility level of visiting a destination as a function of the distance and the number of potential destinations; based on a uniform distribution of utility (0.2 to 1.0) and on a polycentric urban system

When we construct the same figures as in Sect. 4, we find some eye-catching differences between the results for the polycentric system and the results for the monocentric system. Fig. 8 is the polycentric equivalent of Fig. 3.

The first difference between Fig. 8 and Fig. 3 is that in the polycentric case the curves start off with a steeper slope. This is due to the fact that the number of potential destinations M is distributed over a smaller surface (the total surface of the 4 centres in the polycentric urban area is 25% of the surface considered in the monocentric approach). Therefore, the chance that one will find a destination with a high utility in one's vicinity is relatively large. This explains the steeper slope in the beginning of the curves. A second difference between Fig. 3 and Fig. 8 is that Fig. 8 doesn't show the same smooth lines that can be seen in Fig. 3 (except for the unstable pattern between a distance of 0 and 100). The explanation for this difference can best be shown with the help of Fig. 9.

Fig. 9 is the polycentric equivalent of Fig. 4. We see that this graph has two tops, this follows from the specific urban structure depicted in Fig. 7. This density of potential destinations explains the above-mentioned second difference between Fig. 3 and Fig. 8. Fig. 10 is comparable with Fig. 5.

There are no clear differences between Fig. 5 and Fig. 10, representing the expected net utility of trips. The only difference that seems to exist between the two graphs is that the lines in Fig. 5 lie on a slightly lower level than the lines in Fig. 10. This can be explained by the fact that –as mentioned above– for the polycentric case the number of potential destinations M is distributed over a smaller surface. Finally we consider the impact of urban form on the distribution of travel distances (Fig. 11 versus Fig. 6).

These distributions are rather different. In a compact urban area we find the usual unimodal distribution of travel distances shown in Fig. 6. However, as shown in Fig. 11, such a result is no longer obvious in a polycentric setting. Especially when the total number of destinations is small, the polycentric spatial structure has a notable impact on the distribution of

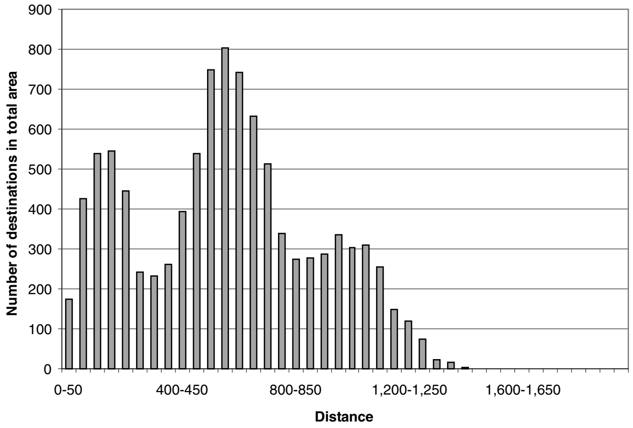

Fig. 9. The density of potential destinations, based on the urban system depicted on Fig. 7

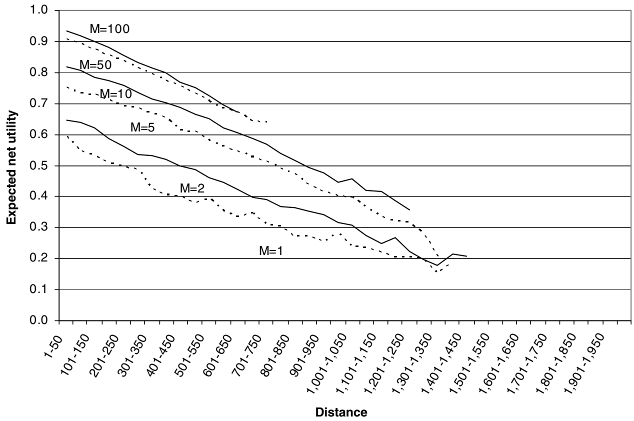

Fig. 10. Expected net utility of visiting the best destination as a function of distance and the number of potential destinations, based on a polycentric urban system

travel distances utility maximising individuals would generate. In the case of Fig. 11 we observe for example, a tri-modal distribution. When the total number of possible destinations gets higher (M close to 100), this multimodal nature disappears since the most attractive destination can be found within the nearest centre anyhow. Empirical distributions of travel distances for a country usually have a unimodal shape, even though they are based on polynuclear patterns. In addition to the reason mentioned above when the number of potential destinations is large, there is still another possible explanation. Most countries consist of a set of settlements with widely varying sizes (remember the rank-size rule) and that are located at varying mutual distances. This leads to rather different and irregular distributions of potential distances travelled by any individual person. However, the aggregate of these distributions will tend to a unimodal distribution of distances travelled.

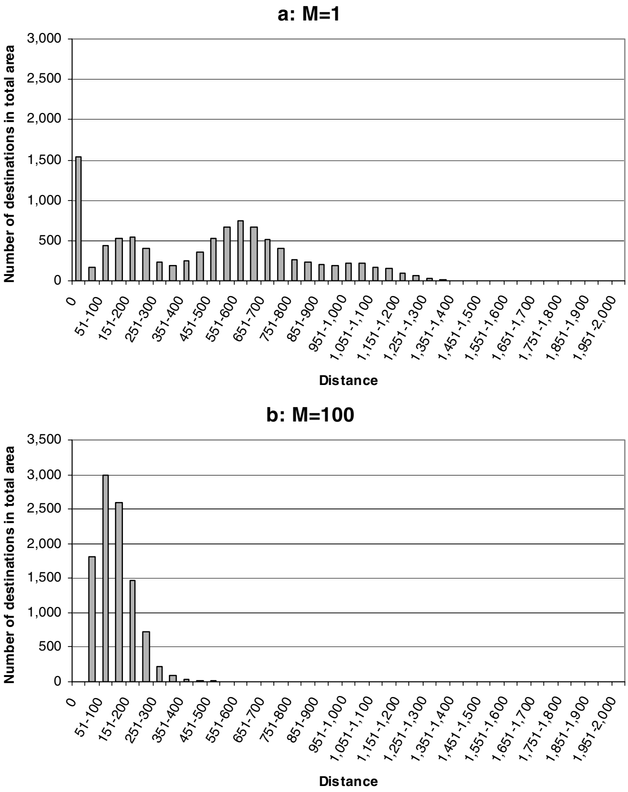

Fig. 11a, b. The distribution of destinations with the highest net utility according to distance, based on the urban system depicted on Fig. 7

6 Conclusions

We conclude that the above approach yields a satisfactory basis for the common practice of including distance travelled in utility functions as a source of welfare. The spatial distribution of destinations and the distribution of their utilities are implicitly present in the formulations derived in sections 2 and 3. Thus, the utility function formulated in section 1 can be considered as a reduced form where these underlying distributions are taken on board. The conclusion is that in the context of estimation the parameter related to distance in Eq. (1) is not purely reflecting preferences, but that it also represents elements of the spatial distribution of destinations and of densities (as reflected by the parameter M). Also the quality level of destinations and variations in the quality of destinations (represented by the parameter a) play a role.

The obvious advantage of Eq. (1) is that it can be used without the need to specify the spatial distribution of destinations. For many applications where Eq. (1) is used data on the distances of relevant destinations of each individual are not known. The disadvantage of the use of Eq. (1) is that it has a reduced form character so that the parameter related to distance reflects several things at the same time which cannot be disentangled without further information. An implication is that transferability of model parameters from one case to the other becomes a complex issue. Therefore, when spatial data are available at the individual level, explicit destination choice models are to be preferred above the reduced form approach mentioned here.

The analysis also sheds light on the paradox that highly educated workers tend to have long commuting distances. Given their high value of time one would expect short commuting distances, but the low spatial density of their jobs and the considerable heterogeneity appear to dominate the outcome.

In the present analysis we focussed on only one particular type of destination. When more than one transport motive is considered Eq. (1) should be generalised to become

$$U = U(d_1, d_2, \cdots, d_N, Y\text{- } c[d_1 + \cdots + d_N], T\text{- } t[d_1 + \ldots + d_N])$$

where d is the total distance travelled, defined as the sum of all distances d_n travelled for all motives $n = 1, 2, \ldots, N$. The different parameters to be found for the different travel motives will represent both the priority attached to the respective activity, the spatial distribution of the destinations and the distribution of utilities across destinations and the absolute number M of destinations available.

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